DETAILED DESCRIPTION OF THE INVENTION

A FIRST EMBODIMENT

1. The first component to be described is a reduced size printed dipole antenna element, as depicted in ~~Figures 1 and 2. Figure 1 depicts~~ Figure 1a, Figure 1b, Figure 2 and Figure 2b. Figures 1a and 2a depict the front side of the element, and ~~Figure 2 depicts~~ Figures 1b and 2b depict the reverse side. As Illustrated in Figures 1a and 1b, the ~~The~~ reduced size printed dipole antenna element consists of a dielectric substrate (7), with patterned ~~metallized~~ regions (for example, metalized regions) (8) which can be formed by any of the processes commonly used to form printed circuits. As illustrated in Figures 2a and 2b, the ~~The metallized~~ patterned regions on the front side form a linear, driven conductor (30) with a feed point (40) at the center, as well as end loading patches (20). Slots (50) are cut into the end loading patches in order to effectively extend the length of the linear driven conductor. Although the patches are shown as being rectangular in shape, similar performance can be obtained with other shapes, for example, round. The loading patches have the effect of lowering the first resonant frequency of the antenna for a given length; or, conversely, reducing the length required to obtain resonance at a given frequency. However, this length reduction, if used alone, tends to reduce the radiation resistance of the antenna, leading to poor impedance match and lower efficiency. It also decreases the bandwith. These effects can be compensated by the placement of a ~~second,~~ linear, undriven conductor (33) on the reverse side of the substrate, electrically connected to the driven conductor through ~~vias~~ via holes (10) in the substrate. In the preferred embodiment, the via hole connections are at the ends of the antenna, to form a folded dipole. In other embodiments the position of the holes

could be moved to another position along the antenna to modify the impedance. The folding effected as described increases the input impedance, and thus the radiation resistance. If the ~~strips~~ driven conductor strip and the undriven conductor strip are of equal width the radiation resistance increases by a factor of four; by varying the widths different multiplication factors can be obtained. The driven and undriven conductor strips also form a parallel strip transmission line with dielectric loading due to the substrate. The dielectric has the effect of reducing the velocity of the transmission line. By proper selection of the dielectric constant and length of the antenna, the transmission line can be made antiresonant at the same frequency at which the antenna structure is resonant. The combination of ~~the~~ antiresonance and resonance allows the antenna to have a double-tuned response, and a bandwidth which is greatly improved over a simple resonant response.

In a typical design for operation at 2.45 GHz, the length of the antenna is 1.2 inches, the width of the conducting strip is 0. 16 inches, the patch measures 0.4 inches by 0.5 inches, and the slots are 0.02 inches wide by 0.16 inches long. The substrate is 0.031 inches thick with a dielectric constant of 4.7. The antenna is typically half the length of a conventional antenna at this frequency. However, modification of these dimensions is clearly possible to suit various applications; in particular, the design can be easily scaled to any operating frequency using formulas available in textbooks and known to skilled ~~practioners~~ practitioners. ~~The antenna is typically half the length of a conventional antenna at this frequency.~~

A SECOND EMBODIMENT

2. The second component to be ~~desribed~~ described is a reduced size printed monopole antenna element based on the same principles, the front side of which is depicted in Figure 3. It is identical to the reduced ~~sizd~~ size dipole antenna element described above except that only half of the structure is used, and this half is mounted over a conducting ground plane ~~(5)~~ (9), with plane of the antenna substrate (7) perpendicular to the conducting ground plane. The driven element (30) can be excited by a conductor (90) fed through the ground plane. The undriven element on the reverse side is connected directly to the ground plane. Again, by varying the relative widths of the two conducting strips the impedance level can be adjusted, and by proper selection of the antenna length in combination with the dielectric constant of the substrate a broad double-tuned response can be obtained.

A THIRD EMBODIMENT

3. The third component to be described is a parasitic (also known as passive) reduced size printed dipole antenna element, the front side of which is depicted in Figure 4. The element (31) is identical to the front side of the reduced size printed dipole antenna element of the first embodiment described ~~in part 1 above descibed~~ above and shown in Figures 1a, 1b, 2a and 2b, except that the ~~second~~ undriven .conductor, the feed point and the via holes are omitted. The reverse side needs no patterning or metallization and can be left completely bare ~~of metal~~. A number of these parasitic reduced size printed dipole antenna elements can be used in conjunction with the reduced size printed dipole antenna element described for the first embodiment ~~in part 1~~ above and shown in Figures 1a, 1b, 2a, and 2b, to form Yagi-Uda type arrays, as will be described below. For use as a passive ~~reflecting~~ reflector element,

the length is increased (typically by about 10 to 15%) over the length used in the driven element of the dipole antenna described in the first embodiment. For use as a passive ~~directing~~ director element, the length is decreased (typically by about 10 to 15%) below the length used in the driven element of the dipole antenna described in the first embodiment.

A FOURTH EMBODIMENT

4. The fourth component to be described is a parasitic (also known as passive) reduced size printed monopole antenna element. The element is identical to the front side of the reduced size printed monopole antenna element of the second embodiment described ~~in part 1 above descibed~~ above and shown in ~~Figures 1 and 2~~ Figure 3 except that the ~~second~~ undriven conductor, ~~the feed point~~ the conductor feed, and the via holes are omitted. The conducting element is connected directly to the ground plane. The reverse side needs no patterning or metallization and can be left completely bare ~~of metal~~. A number of ~~the~~ parasitic reduced size printed monopole antenna elements can be used in conjunction with the reduced size printed monopole antenna element described for the second embodiment ~~in part 2~~ above and shown in Figure 3, to form Yagi-Uda type arrays, as will be described below. For use as a passive ~~reflecting~~ reflector element, the length is increased (typically by about 10 to 15%) over the length used in the driven element of the monopole antenna described in the second embodiment. For use as a passive ~~directing~~ director element, the length is decreased (typically by about 10 to 15%) below the length used in the driven element of the monopole antenna described in the second embodiment.

A FIFTH EMBODIMENT

5. The fifth item to be described is a Yagi-Uda type array formed from combinations of the elements described in the previous paragraphs. In the same manner as conventional dipoles and monopoles, the reduced size printed antenna elements described above can be combined in antenna arrays of any type, using methods that are ~~be~~ familiar to skilled ~~practioners~~ practitioners.

In the ~~one~~ embodiment of the invention, depicted in Figure 5, the elements of the array are coplanar and can be conveniently printed on a single substrate ~~(7)~~ (7g). An enlarged version of the parasitic reduced size printed dipole element described ~~in part 3~~ for the third embodiment above is used as a ~~reflecting~~ reflector element (3a), while one or more smaller versions of the same element are used as director elements (3b). A reduced size printed dipole element as described in part 1 above is placed between the ~~reflecting~~ reflector element and the director elements and is used as the driven element (5). The spacing between the elements is typically about 0.2 wavelengths. The spacing can be varied in conjunction with the lengths of the reflector and director elements in order to adjust the gain, pattern, and frequency response of the antenna. Performance substantially comparable to conventional Yagi-Uda arrays is obtained, with a narrow beam radiated along the array axis in the direction of the director element and reduced radiation in the direction of the reflector element. A front-to-back ratio of 15 dB can be readily obtained.

A SIXTH EMBODIMENT

In another embodiment, depicted in Figure 6, the elements are printed on separate substrates transverse to the array axis. Both configurations can yield a directive pattern

with good front-to-back ratio.

It should be noted that both of the embodiments of the Yagi-Uda array can be implemented effectively using the monopole versions of the driven and parasitic elements, as described in ~~parts 2 and 4~~ the second and fourth embodiments above.

A SEVENTH EMBODIMENT

6. The ~~sixth~~ seventh item to be described is a broadside array formed from combinations of the elements described in ~~the parts 1 through 4~~ the first four embodiments. A typical embodiment is shown in Figure 7, and consists of a number of driven reduced size printed dipole antenna elements (5) as described in ~~part 1~~ the first embodiment, positioned on a single substrate (7a). In ~~the~~ a preferred embodiment the elements are spaced equally, typically with a spacing of not less than one-quarter and not more than one-half wavelength; however, unequal spacings and spacings outside the typical range may be used.

A method for feeding the broadside array is depicted in Figures 8 and 9, with Figure 8 showing an overall view and Figure 9 a cross section detail. A second substrate (7b) is mounted perpendicular to the first substrate ~~(7a), and has formed on it a metallized~~ (7a). A pattern of parallel strip transmission lines (70), is positioned on substrate (7b) such that ~~that is, transmission lines with~~ strips of transmission lines on one surface of the substrate (7b) are parallel to ~~facing each other on either~~ strips of transmission lines on the other surface of ~~the~~ substrate (7b). Transmission lines (70) comprise the narrower transmission lines (72) and the wider transmission lines (75). In the preferred embodiment, narrower and thus higher impedance transmission lines (72) are used to feed the outer elements (5) on substrate (7a) and wider and thus lower impedance transmission lines (75) are used to feed the inner

elements (5) on substrate (7a). By proper selection of the widths of the transmission lines the impedances can be arranged such that substantially equal power is distributed to each element in the broadside ~~array, and~~ array. And, by proper selection of the line lengths, taking into account the dielectric constant of the substrate material (7b), the drive to each element can be made to be substantially in ~~phase; the~~ phase. The combination of equal power and phase ~~giving~~ gives high gain broadside radiation.

By slight modifications of the widths, a tapered amplitude distribution can also be obtained to ~~reduced sidelobe~~ reduce sideload levels at the cost of reducing the gain. At the center, a perpendicular feed line (78) is added to step the overall impedance up to a level suitable for feeding from standard coaxial cables, using a connector mounted at a feed point (60).

The transmission lines (72) and ~~(78)~~ (75) are connected to the feed points of the driven elements (5) at the point where the antenna substrate (7a) and feed substrate (7b) join, typically ~~though~~ through solder joints at the junctions, although any electrical connection type may be used.

The broadside array will yield a vertical fan-beam radiation pattern that is much more narrow in the horizontal plane ~~that~~ than in the vertical plane. This will ease mounting and alignment difficulties in usage of antennas in applications such as client side radios in wireless networks, since the antenna mount only needs precision adjustment in one plane.

Thus the antenna could be mounted on a simple pole that could be rotated to point it towards a base station. In a typical embodiment with four elements both substrates (7a) and (7b) have dielectric ~~constant~~ constants of about 4.0 and the spacing of the elements is

approximately 0.5 free space wavelengths, with the narrower lines (72) having a characteristic impedance of about 100 ohms and the wider lines (75) having a characteristic impedance of about 50 ohms, and the center feed line (78) having a characteristic impedance of about 37 ohms, resulting in a beamwidth of approximately 16 degrees.

AN EIGHTH and NINTH EMBODIMENT

7. The ~~seventh item~~ eighth and ninth items to be described ~~is an array~~ are arrays combining broadside and Yagi-Uda techniques. The ~~array~~ arrays can take many different forms. Two particular embodiments are described here.

The ~~first embodiment,~~ embodiment shown in Figure 10, comprises three or more antenna substrates (7c, 7d, and 7e) and one feed substrate (7f). Substrates 7d and ~~7e~~ 7f ~~form the broadside array described in the previous part,~~ and the elements positioned on substrates 7d and 7f are assembled in a way similar to that described in the seventh embodiment and illustrated in Figures 8 and 9 for the substrates 7a and 7b and the element positioned on substrates 7a and 7b. Substrate 7c has positioned on it a number of enlarged versions of the parasitic elements described ~~in part 3~~ in the third embodiment, with spacings equal to that on substrate 7d, with each element on 7c serving as a reflector for the corresponding element on 7d. Substrate 7e has positioned on it a number of smaller versions of the parasitic elements described ~~in part 3~~ in the third embodiment, with spacings equal to that on substrate 7d, with each element on ~~7e~~ 7e serving as a director for the corresponding element on 7d. Additional substrates with director elements of the type used in 7e can be added to extend the Yagi-Uda array effect.

The ~~second embodiment,~~ embodiment shown in Figure 11, comprises a number of single substrates (7g), each containing a Yagi-Uda array of the type described on the fifth embodiment and shown in Figure 5. The individual arrays are placed such that the substrate planes are parallel but displaced, and distributed along an axis perpendicular to both the individual ~~array axes~~ arrays and the ~~redcued~~ reduced size printed dipole antenna elements themselves. A feed substrate (7h), substantially identical to the ~~type~~ feed substrate (7b) described ~~in part 6~~ in the seventh embodiment and shown ~~as 7b~~ in Figure 8, is used to feed the driven elements of the individual arrays with approximately equal amplitude and phase, although the amplitudes could be tapered by modification of the feedline widths.

In both cases, the result is to obtain increased gain by combining the Yagi-Uda effect with the broadside array effect. Again, a narrow vertical fan beam can be obtained due to the broadside array, while the Yagi-Uda arrangement increases the forward gain and yields a high front-to-back ratio.

8. While the present invention has been described with reference to a few specific embodiments, the description is illustrative and is not to be construed as limiting the invention. Various modifications may occur to those skilled in the art without departing from the true spirit and scope of the invention as defined by the appended claims.